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DOI: 10.1017/S1431927606065809

Microsc Microanal 12(Supp 2), 2006

Instrumentation Developments in Atom Probe Tomography: Applications in Semiconductor Research

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Recent developments in atom probe instrumentation have made it possible to characterize critical semiconductor-based structures as well as metallurgical samples with unprecedented field of view and mass resolution. In this article, we describe recent trends in atom probe instrumentation and provide examples of recently developed semiconductor applications.

The combination of significantly improved detector technology, local electrodes, and laser-assisted ionization techniques has enabled atom probe manufactures to provide short flight path, wide field-of-view (FOV) atom probe configurations while preserving excellent mass and spatial resolution [1-2]. The trend in detector technology has been towards a shorter flight path length and greater detector area. The major advantage of this configuration is the capability to produce fields-of-view in excess of 10,000 nm^2. The difficulty of this design is that it requires one to minimize both the energy dispersion and temporal dispersion of ions departing from the specimen in order to maintain good mass resolution. When evaporating ions from a specimen with a pulsed voltage, the energy dispersion can be dramatically reduced by situating a Local Electrode™ near the specimen and applying a temporally sharp electrical pulse [3-4]. When electrically resistive specimens are analyzed (e.g., semiconductors), the voltage pulsing mechanism faces significant obstacles to forming the appropriate fields at the apex of the specimen. In this case, a pulsed laser can be substituted for the voltage pulse in order to produce timed ionization events. In addition to removing the electrical resistivity obstacle, laser-assisted ionization produces virtually no energy dispersion and minimal temporal dispersion of ionization events. The result is a measurable improvement in mass resolution for most specimens.

A field desorption image of aluminum effectively demonstrates the wide field-of-view capability of a recently developed atom probe detector, Fig. 1. The full acceptance angle of the detector is measured at 63.7° based on the pole locations in this image. For a typical aluminum atom probe specimen field evaporating at 8kV in the presence of a local electrode, this angular field of view corresponds to a 165 nm diameter analysis area or ~21,000 nm^2.

In parallel to detector advancements, the atom probe community has recently revisited the concept of laser-assisted field ionization [5]. Newly available ultrafast pulsed laser sources have enabled the acquisition of pulsed laser atom probe data at remarkably high rates. More importantly, the stability of these sources has made it possible to control this once difficult process. Three major advantages have been observed with laser-assisted ionization: improved mass resolution, decreased noise, and the ability to analyze non-conductive specimens. In Fig. 2, we compare the mass resolution of Si peaks for voltage and laser pulsed modes of operation. Not only are the isotopes fully isolated in the pulsed laser data, but the large noise "hump" near the m/c=15 peak is completely removed. In Fig. 3, we show an example application where a SiGe/Si/SiGe multilayer stack is characterized. When compared with SIMS analysis of the same structure, the abruptness of the interfaces is more clearly shown by the pulsed laser atom probe. In combination with the improved detector technology, the new generation of pulsed laser atom probes has made it possible to quickly and repeatedly analyze semiconductor structures such as the SiGe multilayer stack shown here.

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[2] Deconihout et. al., Surf. Int. Anal., In press.
[3] Kelly et al., Ultramicroscopy, vol. 62 (1996) pp. 29-42. NSF DMR-8911332
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[5] Kellogg, G.L., and T.T. Tsong., J. Appl. Phys. 51 (2) (1980): 1184-1193.

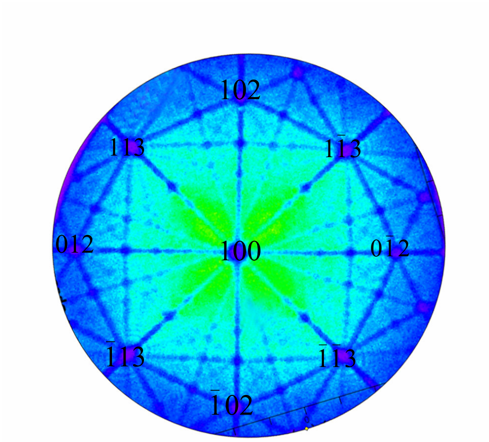

Fig.1. Field desorption image of Aluminum specimen acquired with wide field-of-view detector

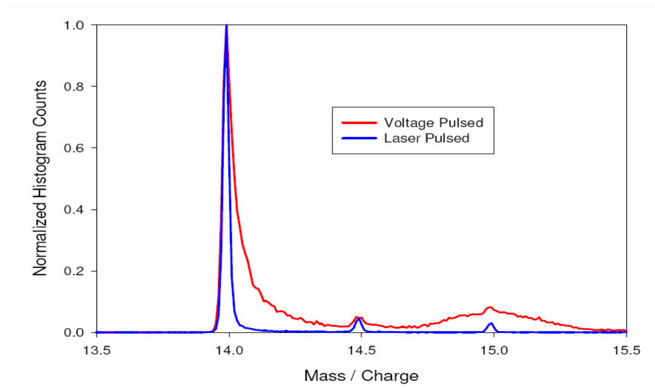

Fig. 2. Comparison of silicon mass peaks for pulsed voltage and pulsed laser assisted ionization.

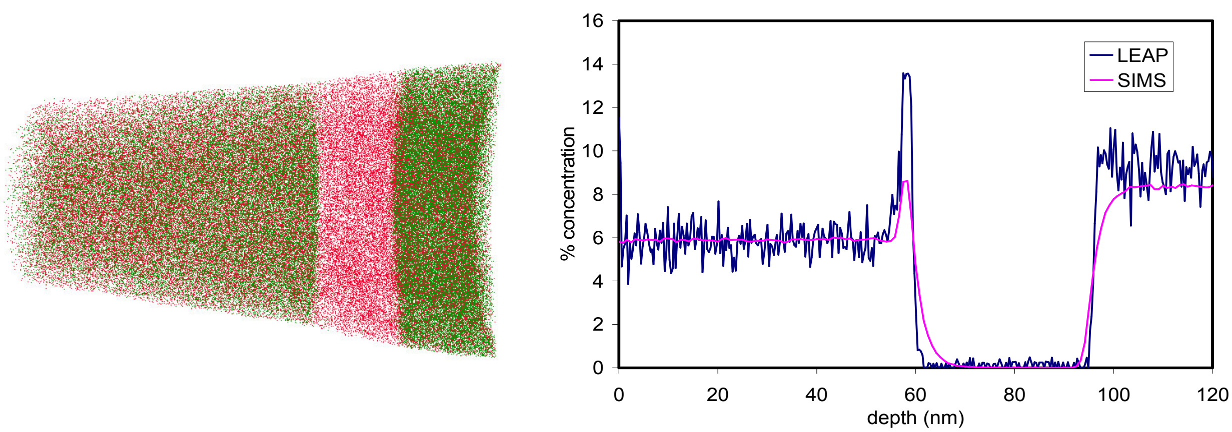

Fig. 3. SiGe/Si/SiGe multilayer stack analysis using a pulsed laser atom probe. SIMS characterization of the same structure is compared on the right.

https://doi.org/10.1017/S1431927606065809 Published online by Cambridge University Press